THE COMING REVOLUTION IN BUILDING DESIGN

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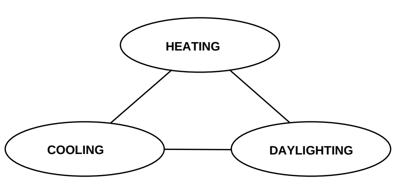
Abstract

We are on the verge of a revolution in building design. Strategies and materials are at hand that can be integrated into modern buildings that consume much less energy to operate, pollute far less, are much more reliable and livable, and cost no more to construct than buildings based on contemporary practice. Success requires a systematic approach that starts in predesign and continues through the design process to construction and operation. The key ingredient required to achieve success is a tool that makes it easy for a designer to understand the consequences of his or her decisions as the design evolves and that can be used to verify performance during commissioning and operation. The proper balance of strategies and their correct implementation is complex, depending on building use, climate, and the local context. Conflicts between issues such as needing solar heat in the winter, avoiding solar heat in the summer, obtaining sufficient natural light, and selecting appropriate equipment, can be resolved through the most effective use of design elements. Daylighting emerges as the design driver in most commercial and institutional buildings. Cost savings resulting from downsized HVAC equipment pay for other improvements. The design tool makes it possible to evaluate these interrelated issues in a comprehensive way. Monitored results from many successful designs show that savings of more than 50% in annual heating, cooling, and lighting energy costs can be achieved through making good decisions during design—without any increase in the construction cost—resulting in buildings that provide better living and working environments for their occupants.

THE COMMENCEMENT

I am particularly honored to receive the PLEA Lifetime Achievement Award because it is bestowed by a peer group that I admire and respect. The participants in the PLEA network are dedicated to an important concept—designing low-energy buildings that sit more gracefully in their environment, deplete fewer of the earth’s resources, cause less pollution, and better serve their purpose as living and working habitats for people. You are dedicated individuals that gather to share your knowledge and learn from one another, to address the particular concerns of your host country, and to refresh your commitment to the principles of the PLEA.



This paper builds on my previous PLEA offerings, particularly on the presentation of *Integrated Design* that was incorporated into the European video produced in Athens in 1994 [1-2] and my paper on *Integration of Heating, Cooling and Daylighting*, presented at Porto in 1988 [3]. In developing these themes, I stressed the need to systematically consider the three-way interaction between the heating, cooling, and lighting needs of a building. I showed that, contrary to conventional wisdom, major reductions in all three loads can be achieved through good design. I presented hard evidence from many monitored buildings that prove that this is not only possible but results in a more livable environment without an increase in initial cost.

Today I will expand the systems approach to a broader consideration of issues, explain how evaluation must parallel the design process from the very beginning, and consider the profound implications to future building design.

This address is not intended to be the synopsis of a lifetime of work. Rather, it is the beginning of a renewed commitment. Like a commencement address to a graduating class, my job is not so much to congratulate this audience on reaching a milestone as it is to articulate a charge to each of you. Go back to your places of work with a fresh determination to disseminate the PLEA principles, and go forward with the belief that you can indeed change the world.

THE COMING REVOLUTION IN BUILDING DESIGN

What if buildings could be designed that require half the energy to operate, that pollute half as much, that cost no more to construct, and that provide better living and working environments than contemporary buildings? And what if the secret to this success was better design rather than more sophisticated and expensive gadgetry (which we all love)? One would think that such results would get immediate and widespread attention within the design community. The fact is that both suppositions are true. It is also true that these facts get little attention. Perhaps this news is just too good to be true.

Eventually, however, the news will penetrate even such a tradition-bound enterprise as building design and construction. As the evidence mounts; as more and more designers learn the techniques; as more and more buildings provide evidence that it is not only possible, but relatively straightforward; as societal pressures increase to do something about pollution and greenhouse gas emissions resulting directly from building operation; and as more and more people experience such buildings firsthand, a breaking point will be reached, and these buildings will become the norm.

Experience teaches us that evolution is not the monotonic, gradual, incremental process it seems, but is prone to infrequent, abrupt change brought about by disillusionment, boredom, or irresistible external pressure. Historically, building design has seen such abrupt changes. After such a change, there is a period of refinement and elaboration until the next abrupt change occurs. These revolutionary changes are widely spaced and seldom anticipated. The last major abrupt change in building design was the Bauhaus movement, which began as a pure form, was gradually extended and modified through the international movement, and is now seemingly mired in the current infatuation with post-modern elaboration and ornamentation. It is time for another abrupt change.

Who will be the next Walter Gropius, the Silver Prince who ties it all together? It is hard to say, but the time is ripe[*]. There are many who would step up to the challenge. Of course, it must be an architect (which leaves me out). As with most historical watersheds, it will take the confluence of opportunity and personality to inaugurate a major revolution and create a legend. Certainly, the opportunity exists at this moment in history.

Conflicting issues

Before we can begin a revolution, we should understand and deal with the impediments. Building design is replete with apparent conflicts. These problems won't go away quietly. Consider the following:

1. The design team is required to produce a functional building that can be constructed within budget, but the team works within the restriction of fees that are too small to permit a thorough evaluation of all options.
2. There are few, if any, incentives for either the building designers or the owner to construct low-energy buildings. Moreover, there are many disincentives to energy-saving design that have become imbedded in the system during an extended era of cheap energy.
3. Although a guiding principle of sensible design is to "keep it simple," there are pressures at every turn urging the designer to incorporate more and more complex components, equipment, and controls.
4. Although policy makers and various agencies urge or require designers and owners to consider life-cycle costs, there are few ways for most owners to recover added construction costs through promised future operating costs. (This varies widely with both building type and building owners.)
5. Building regulations are the panacea of the bureaucratic mind. They typically focus on prescriptive requirements for components, whereas experience repeatedly shows that optimal design focuses on whole-building integration to achieve the best performance at minimum cost. Moreover, it is not possible to regulate or prescribe good design.

These have seemed like insurmountable barriers. They largely explain why there has been so little progress despite the clamor for change.

Solutions to the conflicts

For every conflict listed above, there exists a solution:

(1) A reward system of performance-based fees has been tried successfully in several buildings. This provides a link between the fee received by the design team and the building energy performance. The team is guaranteed a standard fee if the performance is standard. The fee increases on a sliding scale as the monitored energy use of the building decreases. Typically, if energy use is halved, the fee doubles. In effect, the design team shares in the savings. Tested so far on large buildings, where the monetary consequences of one building are sufficient to cover the added contractual legal expenses, the idea could become routine practice. Performance-based fees provide the incentive needed for the design team to take the extra time to design a low-energy building.

(2) A major added incentive for the building owner is the improved functionality of the building as a better environment for people to live and work in.

(3) The main reasons to "keep it simple" are to avoid the high added cost of complex components, equipment, and controls. Another reason is that added complexity virtually guarantees future reliability problems, and complex equipment is expensive to maintain and repair.

(4) Energy-efficient design makes it possible to reduce the capacity of HVAC equipment. This frees up the money needed to pay for the energy-efficient design. Thus, the building is no more expensive to construct, making the life-cycle argument unnecessary. Taking a whole-building systems approach makes it possible to identify solutions that would not be found through an incremental approach.

(5) Nearly every prescriptive-based building regulation has a performance-based option. Improved design tools will make it possible to exercise the performance option more easily, resulting in buildings that perform better and cost less.

There is mounting pressure to change the way we design buildings. The catalyst to change could come at any time, triggering the revolution. The consequences of escalating pollution are increasingly evident—to the point that the environmental movement is no longer the passion of a few but has become mainstream. The Kyoto Accords of 1997 signal a consensus among developed nations that action must be taken to curb greenhouse gas emissions. The conspicuous consumption of energy that characterizes the economies of these countries will come under increasing scrutiny. Glamorous, high-tech, expensive proposals that are popular but impractical will lose out to practical, cost-effective solutions as the economic realities are appreciated and the urgency to "show me the carbon" mounts.

Among the major energy-consuming elements of the world economy, the buildings sector is a soft target for saving energy simply because buildings have been designed for the last 75 years with almost total disregard for energy efficiency. This is sure to draw attention among policy makers and building owners alike. Add to this the corollary benefits, and the case will be made. Given sufficient incentives, inventive people will find and apply solutions to the conflicts, end run the barriers, and turn problems into solutions.

Daylighting—the design driver

Among design strategies, daylighting—the use of natural light to replace artificial light—fills a unique niche. *It stands alone as the most important design issue.* Because daylighting affects the form and layout of a building, the decision to use it must be made early in the design process. Arguably, the most important reasons to daylight a building are, in decreasing order:

1. To improve the aesthetics of the indoor environment
2. To enhance the productivity of the occupants
3. To decrease peak electric loads
4. To reduce emissions of pollutants from power plants, including CO_2, SO_2, and NO_x, and
5. To save on energy and operating costs.

So, if the focus is only on saving energy, the most critical factors are missed. Usually, daylighting shows up well in a life-cycle cost analysis, but oftentimes other strategies, without collateral benefits, edge it out. Each of these daylighting benefits is elaborated below:

(1) What can one say about the first benefit, improved aesthetics? Beauty is in the eye of the beholder. The fact is, however, that people universally like daylit spaces. It is no coincidence that people want perimeter offices. Daylight adds

[*] It is interesting to note that we hear little about Gropius today. This is not surprising—architects, as well as the general public, are tired of the style and long for a change.

variety, character, sparkle, and vibrancy to indoor spaces. Daylighting is most often designed into a building for its own sake. Good architecture requires the intelligent use of light; "without light, architecture is dead." Like all architectural design, daylighting design is challenging, sophisticated, and complex.

(2) The second advantage, enhanced productivity, has only recently been appreciated. It is well known that the cost of operating a building, accounting for the salaries of the occupants, exceeds the cost of operating energy by a factor of 100 to 1. For example, in the United States salaries are about $1,200 per m^2 per year and energy costs are about $12 per m^2 per year. It follows that if productivity is increased by only a few percent, the economic benefit dwarfs the savings in utility costs. There is ample, well-documented evidence that demonstrates that productivity is increased significantly, absenteeism is decreased, and student test scores are increased in daylit environments. The desirability of daylighting has been accepted in some countries where it is required by regulation. These benefits are slowly being documented, and are gaining acceptance throughout the design community.

(3) Peak electric loads in buildings usually occur from approximately 2 o'clock to 4 o'clock on hot summer afternoons, just when the sun is at its brightest and hottest. This is when electric utilities fire up their expensive-to-operate gas-turbine generators to meet their peak load and when "rolling brownouts" are most likely. This is expensive electricity, often costing two or three times as much as base-load power. This added cost is often passed on to the customer in the form of demand charges or other special tariffs. Daylighting can greatly reduce the peak building load by allowing lights to be dimmed or turned off altogether. A corollary benefit is that the reductions in heat given off by artificial lights, both during the peak and in the hours before the peak, lead to a decrease in the on-peak air-conditioning loads. In a simulation analysis, these effects are analyzed quantitatively and the user can see the results in the hourly plots.

(4) Because daylighting saves electricity used for artificial lighting and air-conditioning, it is especially effective in reducing the emission of greenhouse gasses from power plants that provide that electricity.

(5) Energy savings accrue directly to savings in electric energy and indirectly due to savings in cooling energy. Simulation analysis is particularly effective in evaluating these effects, provided that reduced internal gains due to dimming are taken into account during the thermal simulation.

Building performance involves complex interactions

Because people live and work in buildings, there is a perception, based on familiarity, that building behavior follows simple laws. As a result, fewer resources are applied to understanding building physics than, for example, astrophysics. As a result, we may know more about the phenomena governing the behavior of the interior of our sun than the physical happenings inside our buildings. To many, the term "building physics" is a contradiction, an oxymoron. Yet the phenomena are slow, subtle, and complex. Understanding their behavior is an important first step in designing to reduce energy, improve indoor comfort, and improve indoor air quality. Look carefully, and there is real physics to be done and exciting frontiers to be discovered in our familiar building environment. Here is where we scientists and engineers have something to offer (and this is where I can fit in).

An example of this complexity is in lighting. Daylighting reduces energy use by allowing the dimming of lights. Energy-efficient lights also save energy. Each reduces cooling loads and each affects the other. If a building is daylit, then the energy saving resulting from efficient lights are decreased proportionately. If efficient lights are used, the savings associated with daylighting are similarly decreased. Add building-integrated photovoltaics and there is another interaction with daylighting. Each competes for building façade area, for saving the lighting piece of the energy pie, and for the construction budget. The evaluation must be hour-by-hour because it involves the available sunshine, which depends on orientation, time-of-day, and shading.

Another example is the savings due to improved window performance. Calculating the decrease in heat loss resulting from a reduction in window U-value is straightforward. Seldom accounted for, however, is the increase in indoor radiant temperature caused by an increase in glass surface temperature, which in turn reduces the thermostat setting required to achieve the same level of comfort in the space. The savings in heating energy due to this second-order effect can equal the savings from reduced heat loss.

There are many complex interactions such as these. Sorting them out is inherently complex, requiring sophisticated tools. The most important strategies for saving energy include the following rather diverse options:

Daylighting	Energy-efficient lights
Shading	Improved windows
Natural ventilation	Passive solar heating
Energy-efficient HVAC	Air leakage control
Economizer cycle	HVAC controls
Insulation	Reduced duct leakage
Thermal mass	Photovoltaics
Exhaust-air heat recovery	
Solar air preheat	Solar water heating

Many of these interact in complex ways. The only feasible way to evaluate the overall consequences of the combined application of any combination of these strategies is through hour-by-hour simulation. Historically, these calculations were done on main-frame computers and the results published. The problem with this approach is that there are far too many variables, which all interact in nonlinear and complex ways. Performance depends not only on the strategies and how they are implemented, but on climate, building use, and the local context (such as occupancy patterns).

Good news for designers

Fortunately, we now have inexpensive and widely available computers that can perform the intensive numeric calculations needed to simulate the performance of each building in its context. With the advent of the Pentium-class microchip, it is possible to carry out a billion calculations in about one minute—roughly the number of calculations needed to do one hourly simulation for one zone for one year of operation. With the appropriate design tools, a designer can experiment with different strategies quickly, perform several calculations varying a single design parameter, and home in on an appropriate set of strategies and parameters for a particular building design. Leave the fat books of performance tables, confusing nomographs, and complex charts behind—go straight to the answers, accounting for all the interactions. The computing power required to develop the tables, nomographs, and charts was available only on mainframe computers just a few years ago. That power now sits on everyone's desktop.

BUILDING SIMULATION

We would not think of sending an astronaut into space without simulating the mission hundreds of times so that he or she can learn how to deal with every conceivable failure. Pilots routinely receive similar training on simulators. The military simulates warfare scenarios. Hydrologists simulate water flow through aquifers and engineers simulate reservoir depletion of oil fields. Our children use complex and sophisticated computer games to simulate everything from city development, to futuristic civilizations, to road races, to mortal combat between fantasy creatures.

Yet we seldom use the power of simulation to design our own buildings! Exceptions are structural evaluations and design-day calculations required for sizing of heating, cooling, and air-conditioning equipment. However, the latter only address worse-case situations and give no indication of annual energy use.

For those few buildings that are actually monitored for energy performance, the results are often startling, full of lessons to guide future design. This process is expensive and very inefficient; a typical cycle takes years, by which time the mistakes have been repeated many times, and few designers ever hear about the results anyway.

What if you could study the monitoring results from a building before it is built? This would be efficient, allowing corrections to be made before mistakes are made. Simulation models provide the necessary tool. Building performance is simulated hour-by-hour throughout an entire year of typical operation. The user can repeat the simulation many times, trying different options, using the results as a basis for making design decisions.

As a group that espouses passive and low-energy architecture, members of the PLEA network are well aware of the power of simulation tools. Yet a review of papers presented at past PLEA conferences indicates that only a few individuals routinely use simulation during the design process. If we look at general design practice throughout the world, the situation is much worse—the use of simulation-based tools is the rare exception. Yet the business of building construction is the largest financial enterprise in the world. Energy use in buildings accounts for 30% to 40% of world energy use, 25% to 35% of greenhouse gas emissions, and 60% to 70% of world electricity use. Much of this is needlessly wasted.

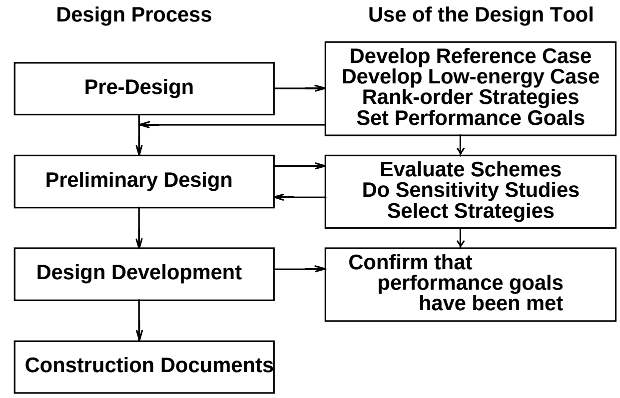
The reason that simulation-based tools have not been used is that *suitable* programs have not been available. Although powerful building simulation programs have been around for more than 20 years, most are user-hostile, intended only for engineers specially trained in their use, and are ill suited to the needs of a designer.

THE DESIGN TOOL CHALLENGE

The key to a successful design tool is to automate as many of the tedious tasks of simulation as possible to make the program easy to use and fast. The program can facilitate many steps, such as (1) automatically developing a reference-case design, (2) automatically modifying the design description to effect the application of energy-efficient strategies, (3) ranking strategies according to their effectiveness, (4) estimating the size of HVAC equipment required to meet design-day loads, and (5) displaying results in an understandable way, preferably graphically. Throughout this process, the program can utilize defaults that have been predetermined by the user, such as typical as well as highly insulated wall sections, conventional as well as advanced windows, and typical building use schedules. A design tool should complement the normal architectural design process as shown schematically in the diagram.

The most critical phase is predesign (sometimes called the programming phase). Energy analysis must start here because energy considerations will very likely affect the evolution of the design. This requires evaluating a building before it is designed. The starting geometry can be a simple rectilinear solid because many energy results depend less on geometrical detail than on other factors, such as internal gains. The initial reference case is developed from a few inputs such as building location (climate and utility rates), building use (office, residence, store, school, etc.), approximate building floor area, and possibly the choice of HVAC system and number of stories. Site constraints may require other inputs. Predesign analysis should include the evaluation of a reference case and various alternatives and prioritizing potential energy-efficient strategies. The designer presents these results to the client and the two parties agree on energy-performance goals for the building. The design can then begin, taking into consideration which strategies should be incorporated. The entire predesign energy analysis should take less than an hour.

There are three key activities that the design tool should facilitate as the preliminary design (sometimes called schematic design) proceeds: (1) the building should be described graphically, using the same sketching tool used to develop the schemes; (2) evaluating various design schemes should be fast, requiring perhaps 15 minutes at the most, and (3) parametric evaluations should be automated. “What-if” questions should be answered quickly: “What if I increase wall insulation?”, “What if I use a different HVAC system?”, or “What if I use continuous dimmers instead of switching to control the backup artificial lighting?”.



By the start of the design-development phase, when energy issues are usually first addressed (if at all), the key decisions that affect energy performance should have been made. Fine-tuning design adjustments will be made at this time. It is essential to ensure that the detailing conforms to assumptions made earlier. Subsidiary design tools will be required to address issues such as thermal bypasses through insulation and glare caused by daylight.

In the construction-documents phase, the user develops specifications as needed to ensure that each element of the building and each piece of equipment will meet their requirements.

We are entering an era with the promise of new tools—tools that meet the challenges of the design profession. The author has been involved in the development of one such tool, the *ENERGY-10* computer program [4 - 5]. This tool meets some, but certainly not all, of the requirements. It is a good first step. Others working on the problem have produced the *Energy Scheming* program and a beta test version of the *Energy Design Advisor*. Each of these developments have taken very different approaches with different results. Time will sort out the best design tools. The good news is that the need is finally being addressed in serious and substantial ways.

BEYOND DESIGN

Building simulation should not stop with the completion of the design process. The tool that provides insight during design can continue to be useful during commissioning, operation, and renovation. While these ideas are still just concepts, they are certainly achievable.

Commissioning

Ironically, buildings themselves are not commissioned: only their systems and subsystems are tested. However, the building-simulation model offers a way to determine if the building as a whole meets specifications. First, the building model is calibrated based on short-term building tests. In this way, the entire building envelope is tested independent of the HVAC system. Gross differences between the original and final model signal problems that should be resolved or remedied before proceeding. Once calibrated, the simulation model serves as an ideal tool for evaluating HVAC performance in situ. This is done by comparing measured performance with performance predicted by the model (using the measured inputs). This determines the end-to-end performance of the HVAC system, including the delivery efficiency of the distribution system. This procedure is more likely to uncover system problems than traditional commissioning techniques.

Operation

Failures in building systems often go undetected for years, resulting in inefficient performance. There is a way to prevent this. The calibrated simulation model can be imbedded into the building energy management system (EMS). Measurements of environmental and occupancy conditions are continuously fed into the model, which calculates the anticipated response of the HVAC system. The measured and predicted inputs to the HVAC system are compared continuously and automatically. Significant differences are flagged, triggering alarms when appropriate. In this way, problems—such as stuck dampers, failed controllers, and inoperative equipment—are detected immediately. Repairs can be made quickly, minimizing adverse effects.

Renovation

Eventually all buildings require renovation. The building outlasts its systems. The record compiled by the building EMS plus the calibrated simulation model can be used to determine the most cost-effective measures to be taken during the renovation. The simulation model is adjusted during the commissioning of the renovation and the process continues.

CONCLUSION

Conditions are prime for a revolution in building design. Tools are being created that can speed the transition to a new era of energy-efficient buildings that provide people with delightful and productive living and working spaces, with much less impact on our fragile environment.

ACKNOWLEDGEMENT

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